REPAIR OF EARTHQUAKE DAMAGED CONCRETE MASONRY SYSTEMS SUBJECTED TO STATIC AND DYNAMIC LOADS AND ELEVATED TEMPERATURES

by

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SYNOPSIS

This paper presents a summary of experimental results[VI] on epoxy repaired concrete masonry components and shear walls. The test parameters include (a) low and high viscosity epoxy adhesives, (b) width of cracks, (c) static and simulated seismic loads, and (d) fire exposure. The test results indicate that masonry shear walls, damaged by earthquakes or other causes, can be effectively repaired with epoxy; the epoxy repaired components being essentially restored to strength levels existing prior to sustained damage under both static and dynamic load conditions. However, under fire exposure, the strength of epoxy repaired components is substantially reduced.

INTRODUCTION

Recent earthquakes, such as the 1971 San Fernando Earthquake, 1972 Managua, Nicaragua Earthquake, and the 1976 Guatemala City Earthquake, have damaged many thousands of concrete and masonry structures. For severely damaged structures or structural components, demolition and replacement are often the only feasible solutions as in the case of many smaller and older concrete and masonry structures in the Managua and Guatemala City earthquakes. However, when repair is feasible and the damage consists of cracks and/or voids, epoxy adhesives have been and are being used extensively for repair (1,2,3). In California, 1,000 to 2,000 structures, mostly reinforced concrete, have been repaired with epoxy adhesives. A significant number of earthquake damaged structures have been or are presently being repaired with epoxy materials in Managua and Guatemala City. Since considerable amount of literature is available on epoxy repaired concrete (2,3,4), this paper will discuss primarily the feasibility and effectiveness of repairing concrete masonry block shear walls damaged by earthquakes or other causes.

For wide cracks, usually more than 1/4 in. wide, an epoxy mixture consisting of epoxy adhesive as a binder and various fillers such as sand

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or cements is most economical. For thin cracks, epoxy adhesives are used alone to obtain adequate penetration. This paper will discuss only repair techniques using unfilled epoxy adhesives.

Epoxy adhesives represent a wide range of chemical polymers with extremely diverse physical properties (5,6). This research program is centered on a low viscosity (450 cps at 20°C) and a high viscosity (15,000 cps at 20°C) epoxy adhesives with compressive and tensile strengths of 1,200 kg/cm^2 and 700 kg/cm^2 at 20°C, respectively. The unique advantages of epoxy repair techniques include (a) minimum repair costs for some damaged structures, (b) minimum loss of utilization of the damaged structure, and (c) little or no change in aesthetic and architectural features. The possible limitations of epoxy repair technique include (a) inadequate penetration and improper curing of epoxy, (b) presence of cavities and (c) sensitivity of epoxy adhesives to temperature.

OBJECTIVES OF THE EXPERIMENTAL PROGRAM

The primary objectives were to determine the feasibility and effectiveness of the epoxy repair for cracked masonry block shear walls. Experimental tests were conducted to investigate the strength properties of epoxy repaired concrete masonry block under static loads, simulated seismic loads and elevated temperature conditions. A total of approximately 240 small scale experimental tests were conducted on individual components within the masonry block wall matrix including block ribs, mortar joints and grout (1).

Block rib specimens (10 cm. x 15 cm.) were sawed from standard 6-in American masonry block (7) and injected with epoxy as shown in Fig. 1. All grout specimens (15 cm. x 25 cm. x 10 cm.) were constructed to approximate the cross-sectional area of the cavity of the 6-in. standard American block. The grout consisted of type M mortar (7) into which sufficient water was added to cause the grout mixture to flow readily. The grout specimens were cracked and subsequently repaired with epoxy similar to block rib specimens shown in Fig. 1. Since cracks often propagate along the masonry joints, epoxy repaired mortar joint specimens (10 cm. x 15 cm.) were constructed as shown in Fig. 2. The large essentially unreinforced shear wall specimens (1) were constructed as shown in Fig. 3. The size of shear wall specimens varied from 16" x 16" to 32" x 24". Since most repaired and unrepaired cracks in damaged masonry block construction in California were measured between 0.05 cm. and 0.25 cm., these two crack widths were adopted for all experimental tests.

EXPERIMENTAL RESULTS AND ANALYSIS

The experimental results indicate that grouted masonry block shear walls can be effectively repaired with epoxy adhesives provided several factors affecting the strength of repaired structures are taken into consideration. First, partial or complete debonding of the grout from the block (due to drying shrinkage) was observed in both laboratory specimens and actual masonry shear wall construction. When the epoxy is injected into cracks, the debonded region will also be filled with epoxy resulting in possibly excessive costs. Second, due to porosity of block material and grout on older masonry construction, the absorption of epoxy by the construction materials can result in cavity formation. In laboratory experiments, such cavity formations reduced strength capacities more than

15%. By choosing epoxy adhesives with appropriate viscosity properties, both of these factors can be either eliminated or reduced so that the epoxy repair technique can be effectively used to repair concrete masonry block shear walls.

All dynamic tests were performed at 3 hertz using the MTS dynamic testing machine and an analog computer to generate a sinusoidal load function with a linearly increasing amplitude. All loads were uniformly distributed along the indicated edge. The load function was designed to produce failure between the 6th and the 12th load cycle. For all static and dynamic tests, failure was initiated in the construction material and not within the cured epoxy adhesive. Within the crack widths tested and when proper curing and adequate penetration of the epoxy is achieved, the width of cracks and the viscosity of the epoxy adhesives do not appreciably affect the strength properties under either static and simulated seismic load conditions.

Tables 1 to 3 provide test results for small scale specimens. Compression test results are shown for crack angles, θ, of 90°, 75° and 60°. Direct shear test results are also included. For nearly all of these experimental tests including direct shear, debonding of the epoxy from the construction materials was not observed. The strength results, including the corresponding standard deviations, are shown in Table 1 for block ribs. The results are relatively independent of crack angle and the dynamic strengths exceed static strength by approximately 24%. Test results for mortar joint specimens are provided in Table 2. The absorption of the epoxy by the type M mortar joint (about 1.0 cm. thick) has the effect of reducing joint thickness and thus increasing the strength of masonry joint specimens. Dynamic strengths were approximately 44% larger than static strengths for masonry joints. Table 3 provides a summary of test results for the grout specimens. For static tests, the direction of the crack angle does affect the strength results appreciably. Furthermore, the standard deviations for grout tests were generally larger than for mortar joint or block rib test results. The dynamic strength values for grouted specimens were approximately 24% larger than the static strength values.

Eight additional static experimental tests were conducted on shear wall specimens with $\theta = 45°$ crack angle as shown in Fig. 3. The average compressive strength was 147.6 kg/cm^2 with a standard deviation of approximately 20 kg/cm^2. Failure mechanism for these shear wall tests often developed in three consecutive stages: (1) debonding of block ribs from grout, (2) column type failure of the debonded block ribs, and (3) compression failure of the grout. Under static and dynamic load conditions, the presence of the epoxy repaired crack does not present a stimulus for crack initiation or crack propagation. Debonding at the epoxy-block wall interface was generally not observed as shown by the crack patterns in Fig. 4.

Current experimental research is centered on the effects of fire on epoxy repaired masonry block and concrete shear walls. The results shown that the shear, bond and tensile strength of epoxy repaired specimens beyond 400°F is nearly zero. Therefore, the nature of thermal gradients determines the strength characteristics of epoxy repaired shear walls during fire exposure. For a 0.25 cm. crack width and a two-hour fire exposure, as defined by the standard ASTM E-119 time temperature curve (8), the epoxy char zone extended to depths of between 2 cm. to 3 cm.

Beyond the char zone, the strength of the epoxy adhesive is a function of temperature. For 6-in. thick concrete or concrete masonry block walls with a 0.25 cm. thick epoxy filled crack and subjected to a 2-hour fire exposure, an 80% reduction in the shear strength of the epoxy repaired assembly can be expected during the fire exposure. However, when the specimens are cooled to ambient temperature, about a 40% reduction in shear strength can be expected. Under both test conditions, debonding failure generally occurred at or very near the epoxy repaired crack indicating that failure of the epoxy material had occurred. Additional research is currently in progress concerning the effects of building fires on epoxy repaired concrete masonry block and concrete components

CONCLUSIONS

Experimental results indicate that concrete masonry block walls can be effectively repaired with epoxy provided several precautions are undertaken concerning porosity and debonding of grout from block ribs. However, under fire exposure, the strength properties of the epoxy repaired structural components is reduced extensively during and after fire exposure.

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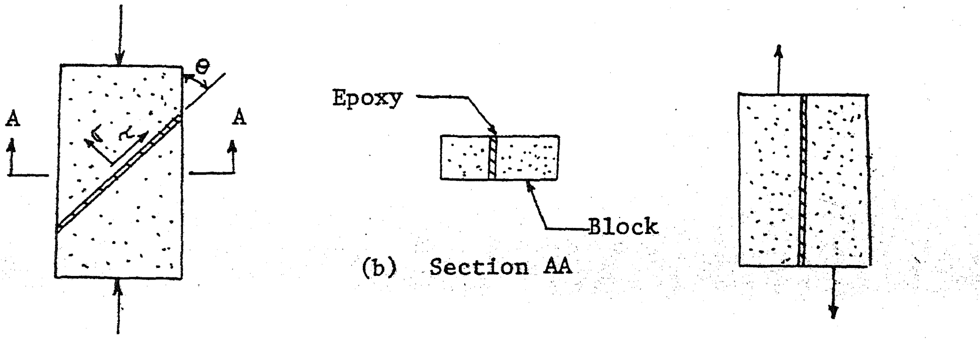
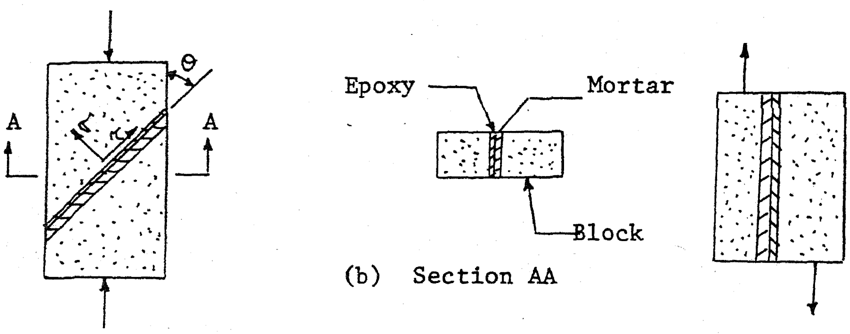


(a) Compression Loading (b) Section AA (c) Direct Shear Loading

Fig. 1 BLOCK RIB SPECIMENS



(a) Compression Loading (b) Section AA (c) Direct Shear Loading

Fig. 2 MASONRY JOINT SPECIMENS

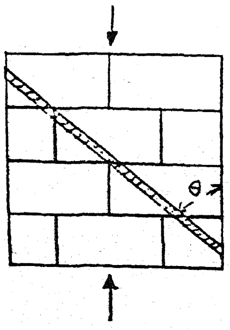


Fig. 3 EPOXY REPAIRED SHEAR WALL SPECIMENS

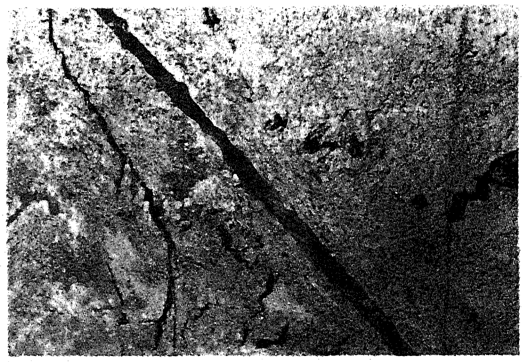


Fig. 4 CRACK FORMATIONS IN EPOXY REPAIRED SHEAR WALL SPECIMENS

Table 1 Compression Strength, Shear Strength and Standard Deviation for Block Rib Specimens

Test Condition	Static Strength (Kg/cm^2)		Dynamic Strength (Kg/cm^2)	
	Average	Standard Deviation	Average	Standard Deviation
Compression -90°	171.8	14.7	238.4	22.3
Compression -75°	210.1	15.6	241.3	24.0
Compression -60°	179.2	13.0	252.3	29.7
Direct Shear	33.5	*	37.5	*

Table 2 Compression Strength, Shear Strength and Standard Deviation for Masonry Joint Specimens

Test Condition	Static Strength (Kg/cm^2)		Dynamic Strength (Kg/cm^2)	
	Average	Standard Deviation	Average	Standard Deviation
Compression -90°	140.7	24.5	209.6	24.6
Compression -75°	161.0	21.7	215.2	18.0
Compression -60°	148.7	24.3	197.8	21.6
Direct Shear	**	**	**	**

Table 3 Compression Strength, Shear Strength and Standard Deviation for Grout Specimens

Test Condition	Static Strength (Kg/cm^2)		Dynamic Strength (Kg/cm^2)	
	Average	Standard Deviation	Average	Standard Deviation
Compression -90°	142.2	11.8	202.9	30.9
Compression -75°	196.5	45.3	195.2	28.6
Compression -60°	228.6	27.6	207.9	20.8
Direct Shear	16.6	*	28.2	*

*Standard Deviation not calculated due to inadequate number of tests.

**Direct Shear strength was nearly zero since failure always occurred at the non-epoxied mortar-block interface.

DISCUSSION

A. Chatterji (India)

Since the authors have concluded that the strength of epoxy resin in bending is greatly reduced under fire exposure, would not the authors agree that it is better to have the damaged parts replaced instead of being repaired by epoxy resin bonding as most buildings are liable to go on fire ?

G.P. Saha (India)

The success of jointing with epoxy or epoxy mortar depends primarily on the treatment of the two joint surfaces. If the surfaces are not cleaned properly then the dust which are present on the surfaces will cause a film of barrier and will prevent bonding of the two cracked surfaces.

Will the authors please let us know how the treatment of the joint surfaces were done.

H.N. Gandhi (India)

The author has mentioned that the epoxy of low and high viscosity mentioned by him is suitable for 400°c. The epoxy manufactured in India based on international specifications (CIBA) is recommended for 100°c only. May the author kindly clarify this.

I.K. Aneja (U.S.A.)

What is the time effect on the strength of epoxy repaired system subjected to dynamic loads under normal and elevated temperatures.

H. Tiedemann (West Germany)

Can the authors offer some guidence on aging properties of Epoxy Repairs e.g. how resistant will the repaired part be after 30 years in a tropical climate.

Author's Closure

Not received.